Dielectric Laser Acceleration

HEPAP Subpanel Review

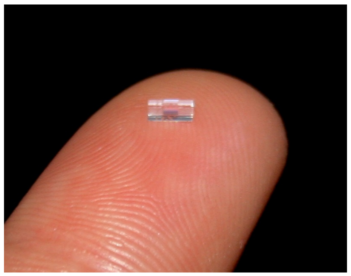
R. Joel England, Aug 29 2014

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

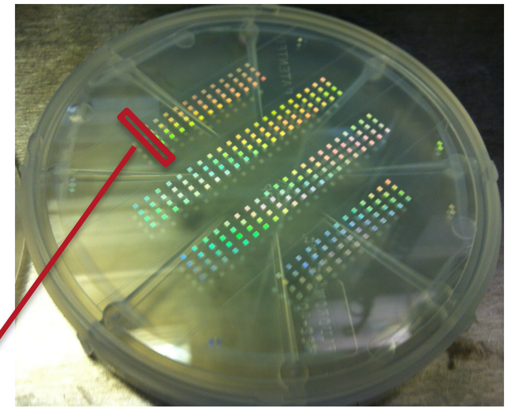
Dielectric Laser Acceleration (DLA) Concept

SLAC



laser-driven microstructures
- **lasers:** high rep rates, strong field gradients, commercial support
- **dielectrics**: higher breakdown threshold → higher gradients (1-10 GV/m), leverage industrial fabrication processes

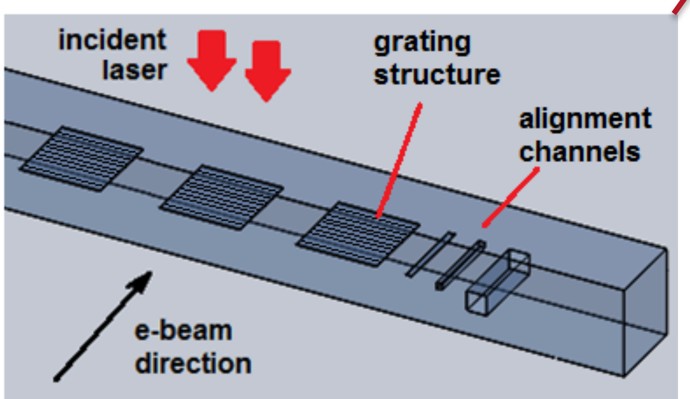
"Accelerator-on-a-chip"

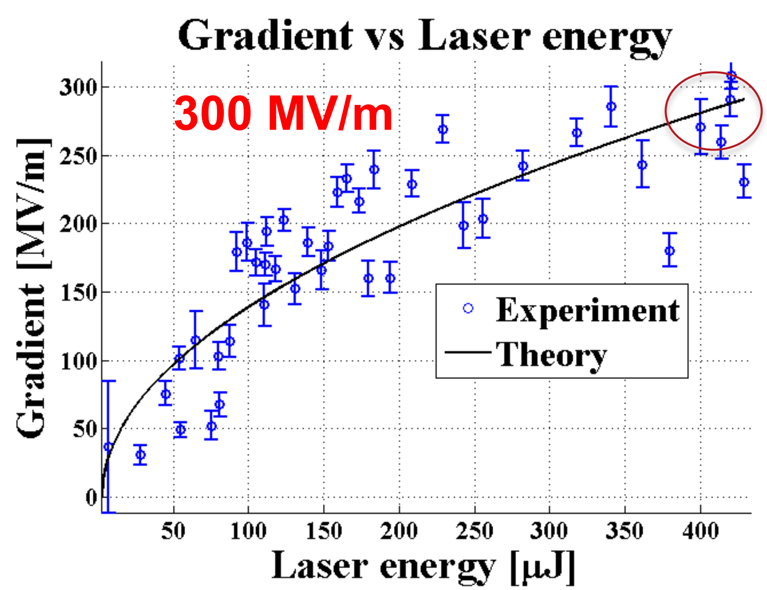


bonded silica phase reset accelerator prototypes fabricated at SLAC/ Stanford

Goal: lower cost, more compact, energy efficient, higher gradient

Wafer is diced into individual samples for e-beam tests.





SLAC E-163 Program

Developing new accelerator technologies is a key goal of the DOE/HEP mission.

> *"Develop a greatly expanded accelerator R&D program that would emphasize the ability to build very high-energy accelerators beyond the High-Luminosity LHC (HL-LHC) and ILC at dramatically lower cost."* ***- P5 Executive Summary 2014***

E163 Program Objective is to develop DLA for high gradient (GV/m), low cost, and power efficient acceleration for HEP linear collider & other applications.

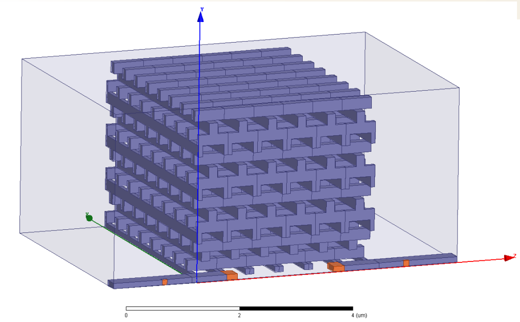
• Demonstration experiments relevant for HEP (energy-scalable, speed-of-light phase velocity) require access to **suitable test facilities** - restricted mainly to national labs (SLAC, LLNL, BNL).

• SLAC/E163 program uses **existing infrastructure** at NLCTA to develop and test prototype DLA micro-devices.

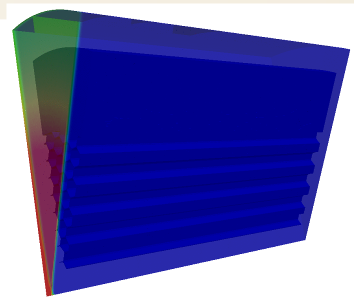
• **Proximity to university** (Stanford) material science and laser expertise as well as industry (laser, nanofabrication) are crucial.

• Recent **successful demonstrations** have expanded interest and set the stage to address energy scaling, new test sources, and a host of potential applications.

SLAC E-163 Program

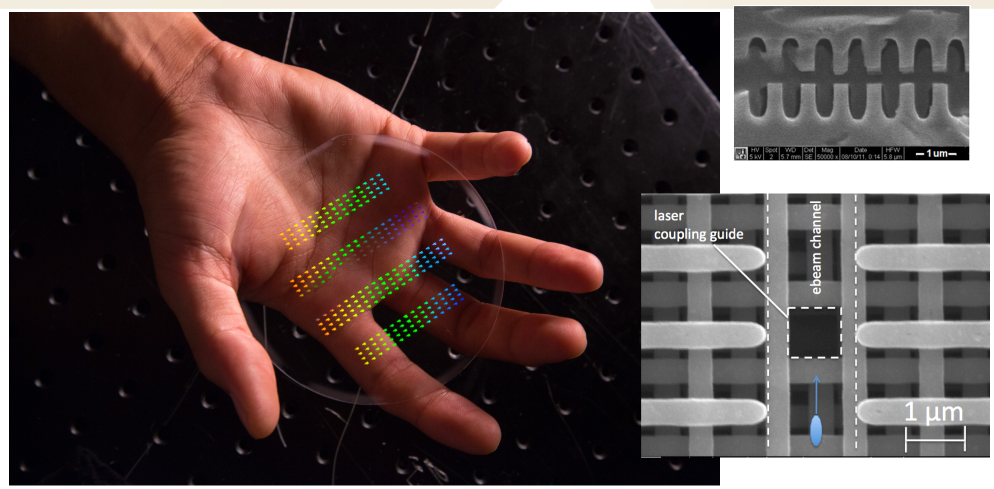


HFSS

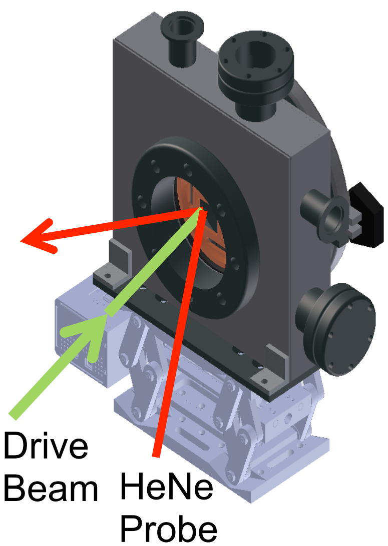


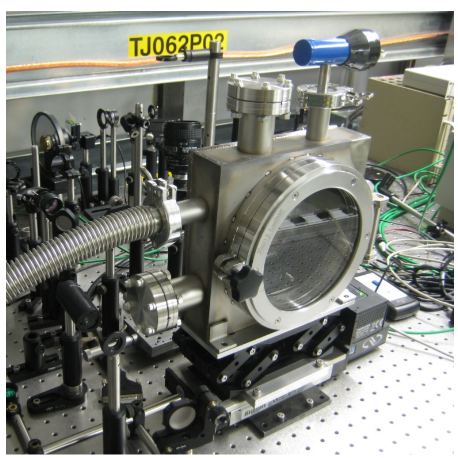
ACE3P

High-End Simulation Capabilities

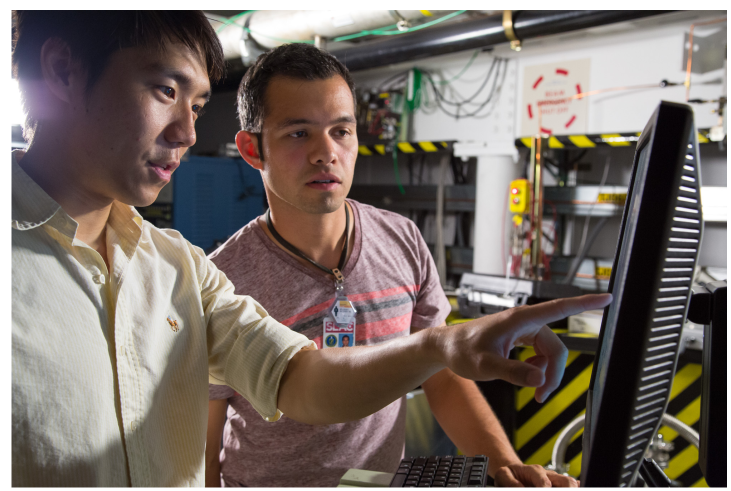


Nanofabrication of micro-accelerators





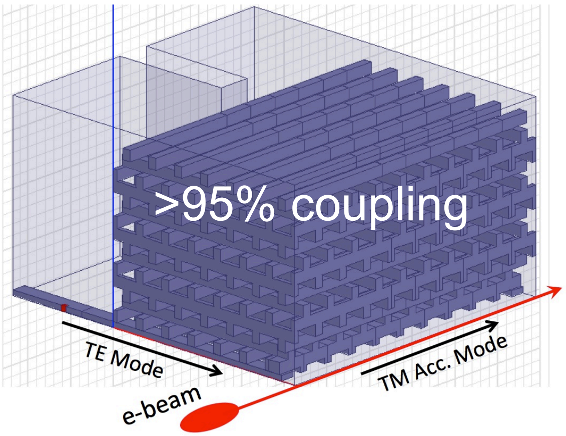
Benchtop Characterization

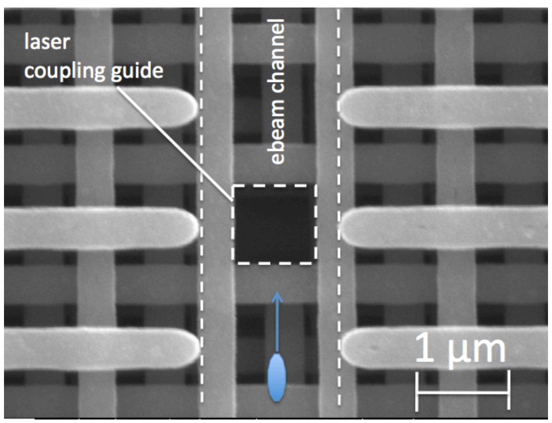


Student led laser+ebeam experiments

Compatible All-Optical Accelerator Subcomponents

Efficient Coupler Designs

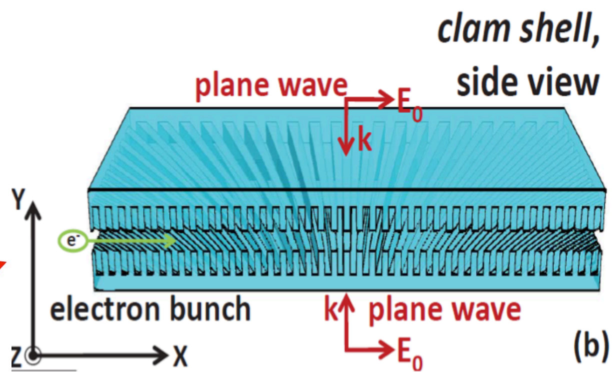




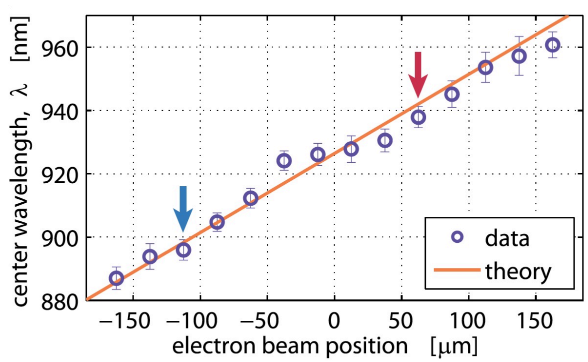
C. McGuinness, Z. Wu

Phys. Rev. ST-AB, **17,** 081301 (2014)

Beam Position Monitor

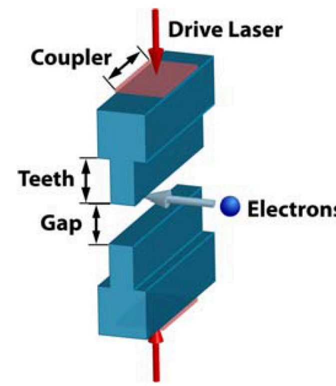


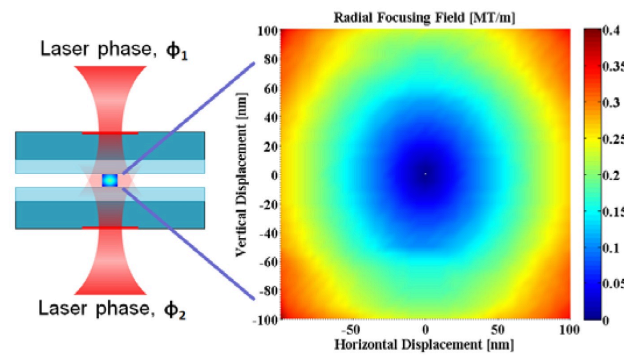
Opt. Lett., **37** (5) 975-977 (2012)



Opt. Lett., **39** (16) 4747 (2014)

Focusing Structures

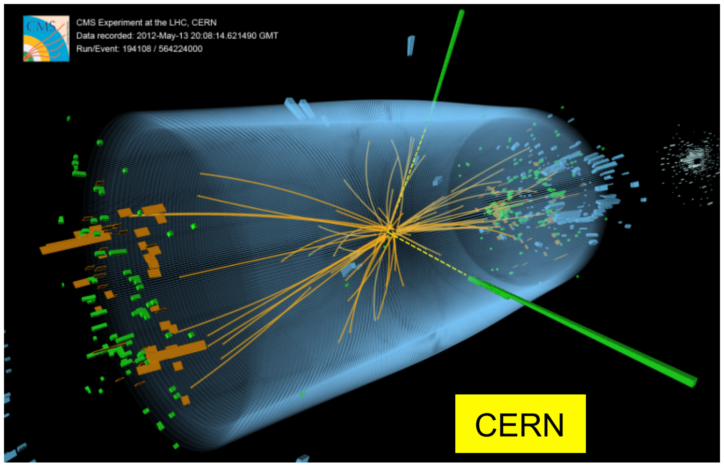




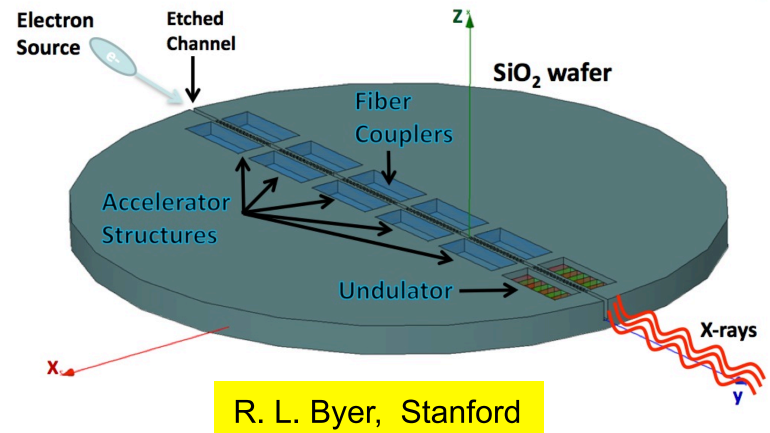
AIP Conf. Proc. **1507**, 516 (2012)
J. Mod. Opt. **58** (17), 1518-1528 (2011)

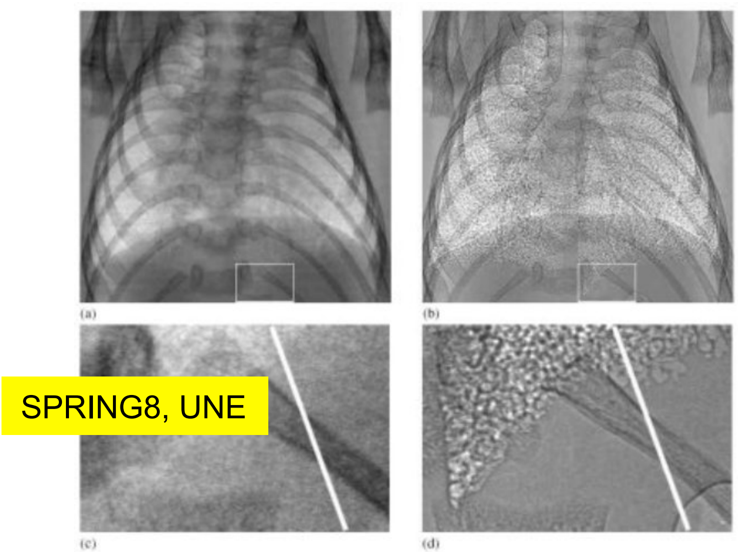
DLA Applications

linear collider or Higgs factory



university-scale light source





medical imaging

portable cancer treatment

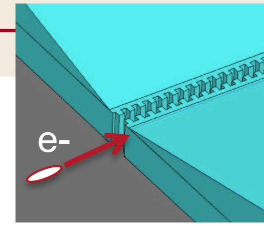
DLA Applications: Linear Collider

P. Bermel, et al, "Summary of the Dielectric Laser Accelerator Workshop," **NIM-A** 734, 51-59 (2014).

SLAC

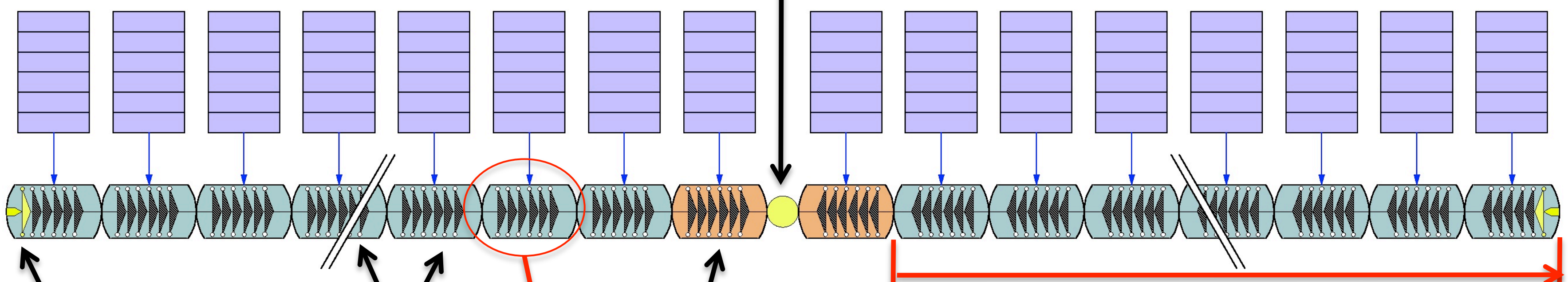
6 fiber lasers per
6" wafer module
2 kW per laser

Thulium fiber laser λ=2 μm



concept for 1 DLA accelerator structure (E. Peralta)

Interaction Point



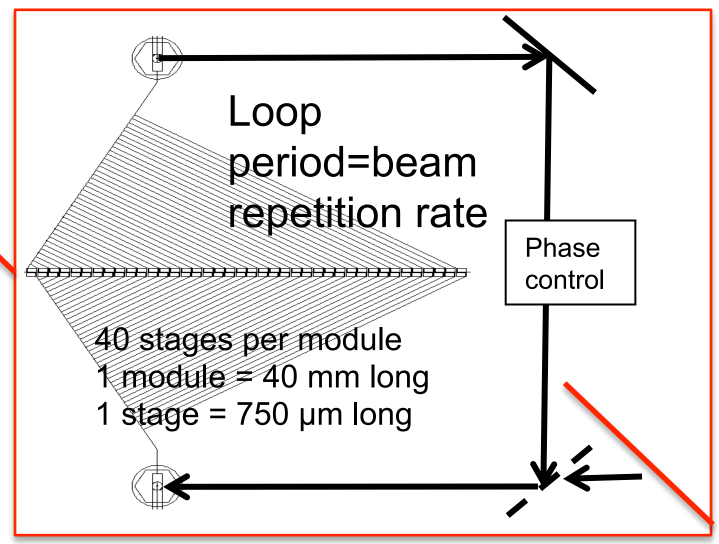
needle emitter and injector module

accelerator wafers

final focus and steering wafers

0.5 TeV ⇔ 500 m ⇔ 15,700 lasers

Parameter	Units	CLIC 3 TeV	DLA 3TeV	DLA 250 GeV
Bunch Charge	e	3.7e9	3.0e5	3.8e5
Rep Rate	MHz	5e-5	20	60
Beamstrahlung E-loss	%	**28.1**	**1.0**	**0.6**
Enhanced Luminosity / top 1%	cm-2/s	2.0e34	3.2e34	1.3e34
Wallplug Power	MW	582	374	152



Various Nearer-Term Applications

Medical: Brachytherapy

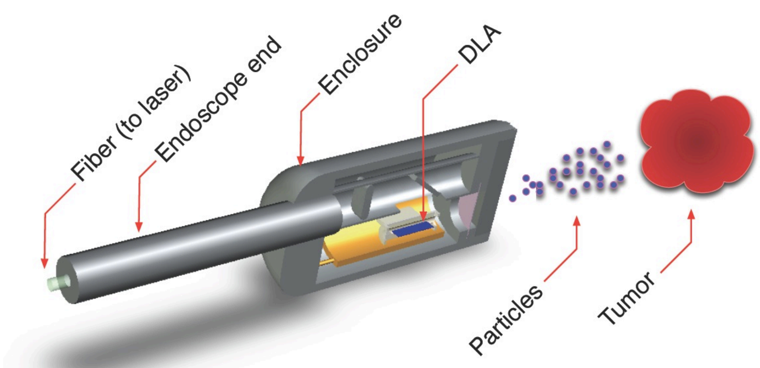
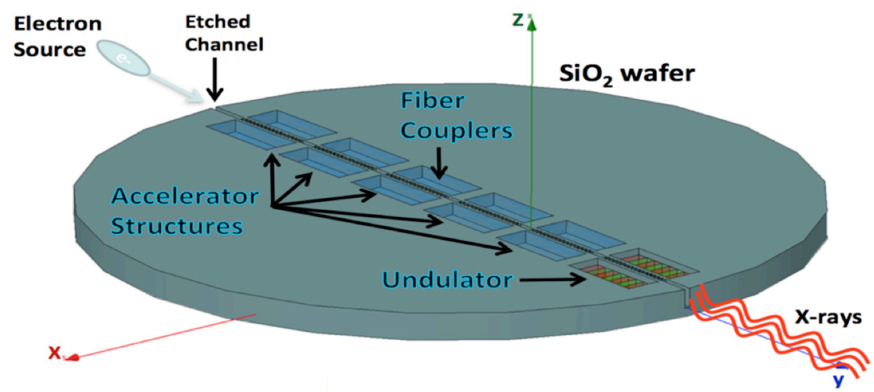


Image courtesy G. Travish (UCLA)

Direct ebeam tumor irradiation

• Improved targeting of tumor site
• Lower dose, less collateral damage
• Inexpensive devices → improved worldwide availability of treatment
• 20 MeV beam with 2000 e- bunches at 50 MHz → ~ 1 Gray/s

XUV Light Source



Wafer-scale XUV source w/ optical unduator

• Same operating principles can be used to make deflectors/undulators.
• Modelocking scheme proposed could enable attosecond radiation pulses (see Z. Huang, AAC14)
• 40 MeV beam, 10 fC, 250 um undulator period → 660 attosec XUV (50 eV) pulse train with 100 nJ/pulse

E163 Recent Progress

SLAC

Electron Beam Demonstration Experiments

→ First demonstration of high-gradient in a DLA structure (at 300 MV/m).

→ First demonstration of compatible optical-scale beam position monitor.

→ First acceleration demonstration in "micro accelerator platform" (UCLA).

Development and Fabrication of Accelerator SubComponents

→ Interferometric demonstration of thermal phase stability.

→ Initial fabrication of silicon accelerators in a single process using membrane stacking.

Benchtop Characterization & Simulation

→ Simulation of a 1000 period DLA in Vorpal with 5M particles (Tech-X).

→ Laser damage characterization of over a dozen robust dielectric materials.

→ Simulational design of a 3D photonic bandgap coupler with >95% coupling efficiency.

E163 Publications in 2014

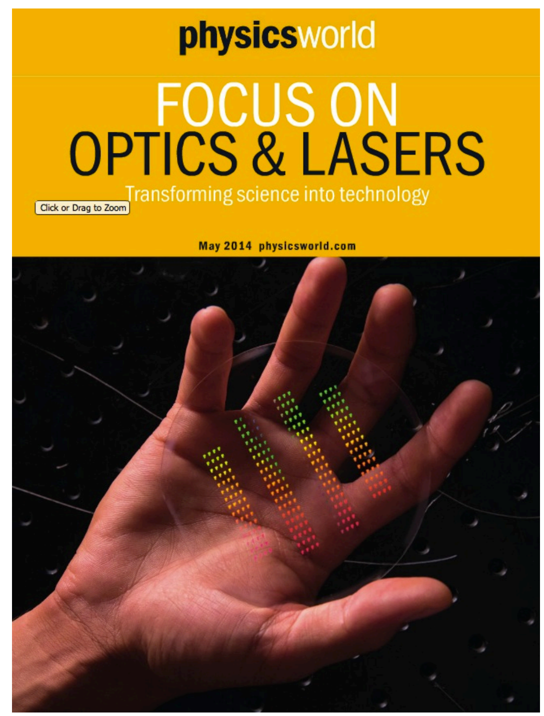
SLAC

LETTER nature

doi:10.1038/nature12664

Demonstration of electron acceleration in a laser-driven dielectric microstructure

E. A. Peralta[1], K. Soong[1], R. J. England[2], E. R. Colby[2], Z. Wu[2], B. Montazeri[3], C. McGuinness[1], J. McNeur[4], K. J. Leedle[3], D. Walz[2], E. B. Sozer[4], B. Cowan[5], B. Schwartz[5], G. Travish[4] & R. L. Byer[1]



E163 Publications in 2014

SLAC

E. A. Peralta, K. Soong, et al., "Demonstration of Electron Acceleration in a Laser-Driven Micro-Structure," ***Nature*** 503, 91-94 (Dec 2013).

K. Soong, E. Peralta, et al., "Electron beam position monitor for a dielectric micro-accelerator," **Optics Letters** 39 (16), 4747-4750 (June 2014).

R. J. England, "How to shrink an accelerator," **Physics World**: Optics and Lasers, 28-29 (May, 2014).

Z. Wu, R. J. England, et al., "Coupling Power into Accelerating Mode of a 3-D Silicon Woodpile Photonic Band-gap Waveguide," accepted for publication, **Phys. Rev. ST-AB** 17, 081301 (2014).

R. J. England, R. J. Noble, eds., "Dielectric laser accelerators," accepted for publication in **Reviews of Modern Physics** (2014).

P. Bermel, et al, "Summary of the Dielectric Laser Accelerator Workshop," **NIM-A** 734, 51-59 (2014).

PhD Defenses

E. Peralta: "Grating-based Dielectric Microstructures for Laser-Driven Acceleration of Electrons" (June 2014)

K. Soong: "Demonstration of Electron Acceleration and Diagnostics with Microstructures" (June 2014)

DLA Timeline

Tasks	Where	FY15	FY16	FY17	FY18	FY19	…..
Optimized structures, net acceleration demonstrations	SLAC				Existing program		
Attosecond Electron Source Development	University						
Extended R&D: developing energy scalable architecture	University						
Commercialization, expanded availability of DLA technology	Industry			Already interest from Varian medical			

FY	SLAC E163 Program Goals thru FY16
2014	Demonstration of **optical BPM** (successful), first electron demonstration experiments of **silicon accelerator structures;** fabrication of deflecting structures
2015	Increased laser pulse energy; demonstrate **laser dielectric steering devices;** begin **net acceleration** using DLA; injector and/or transport lattice upgrades for improved emittance; laser lab rennovation for benchtop testing
2016	First **multiple stage acceleration** prototype tests; increased pulse rate for high-rep power testing; start-to-end simulations for a DLA based collider.

Conclusions

Why at a national lab?

University participation is crucial, but these intial demonstration experiments would not be possible without the focus/infrastructure/leadership of a dedicated national lab program.

Why at SLAC? Who else is pursuing this?

Expertise and strong ties to Stanford; proximity to silicon valley foundries; primary US effort is from SLAC and collaborators. However, numerous international entities are now getting involved (DESY AXSIS, Cockcroft - UK, Uesaka – Japan, Tsing Hua Univ. – Taiwan). Maintaining U.S. lead in this area will require strategic R&D efforts.

Who and what sustains this program in the long run?

Investment from govt agencies (DOE, DARPA,…) and commercial interests (e.g. medical, security).

Connection with other SLAC program and/or Stanford University?

Strong collaborations with Ginzton Labs (Byer, Harris, Solgaard); Z. Huang (SLAC), overlap with HGRF and PWFA programs at SLAC.

Thank you!